Application of Biosecurity in Aquaculture Production Systems

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Abstract

A significant challenge to the expansion of aquaculture production is the outbreak of disease. Potential economic losses from disease outbreaks are significant, and can affect the survival of the industry. The occurrence of disease is a combination of the health of the animal, the condition of the environment, and the presence of a pathogen. The poultry industry has implemented a biosecure production system to prevent the spread of infectious disease among farms. It serves as a model to aquaculture as a reliable source of animal protein worldwide. This paper briefly highlights some of the major points and practices of biosecurity for various aquaculture production systems presented at a special workshop held in Honolulu in July 2001 and published in the proceedings, "Biosecurity in Aquaculture Production Systems: Exclusion of Pathogens and Other Undesirables" (see Lee and O'Bryen 2003). Examples of biosecurity systems used domestically and internationally in shrimp farming, finfish culture, and mollusc culture, as well as regulations and policies to prevent and control the spread of aquatic animal diseases are provided. The key elements of biosecurity are a reliable source of stocks, adequate detection and diagnostic methods for excludable diseases, disinfection and pathogen eradication methods, best management practices, and practical and acceptable legislation.

Introduction

Production from aquaculture has grown at an impressive annual rate of approximately 11% since 1980. One of the significant challenges to the expansion of aquaculture production is from disease outbreaks. Diseases caused by viral infection are not easily treated under current technology and have caused significant economic losses. Potential economic losses from disease outbreaks are significant, and can affect the survival of the industry. For example, viral disease outbreaks have caused billions of dollars in lost revenue for the global shrimp industry (Lightner 2003, **Table 1**). Operation of shrimp farming once became impossible in countries such as Ecuador, Taiwan, and China due to disease outbreaks. The most effective way to deal with viral infection is to prevent it from occurring.

The success of the poultry industry as a reliable source of animal protein worldwide has been due to the implementation of a biosecure production system to prevent the spread of infectious disease among farms. The biosecurity practices in the poultry industry have prompted, in recent years, the consideration of a similar practice in aquaculture to deal with disease problems. The lessons learned from the poultry industry will assist the development of biosecurity in aquaculture.

Table 1. Estimated economic losses since the emergence of certain diseases in penaeid shrimp aquaculture.

Virus	Year of emergence to 2001	Product loss (US dollars)
White Spot Syndrome Virus-Asia	1992	$4-6 billion
White Spot Syndrome Virus-Americas	1999	>$1 billion
Taura Syndrome Virus	1991-1992	$1-2 billion
Yellow Head Virus	1991	$0.1-0.5 billion
Infectious Hypodermal and Hematopoietic Necrosis Virus	1981	$0.5-1.0 billion (includes Gulf of California fishery losses for 1989-1994)

Source: Lightner (2003, p. 85)

The National Oceanic and Atmospheric Administration has provided the Aquaculture Interchange Program (AIP) at the Oceanic Institute in Hawaii with funding to gather information related to biosecurity measures used against the spread of bacterial diseases, viral diseases, and parasites in production systems for major aquaculture species, especially through early detection and prevention. Experts were invited to a special workshop in July 2001 to present information on biosecurity basics, to share their experiences implementing biosecurity practices in the poultry industry, shrimp farming, fish farming, and mollusk culture, to discuss potential air borne vectors of pathogens and transmission of pathogens through gamete exchange, and policy development to prevent and control the spread of disease. Detailed information reported at the workshop can be found in the proceedings, "Biosecurity in Aquaculture Production Systems: Exclusion of Pathogens and Other Undesirables," published by the World Aquaculture Society in 2003 (Lee and O'Bryen 2003). This paper briefly highlights some of the major points and practices of biosecurity for various aquaculture production systems.

Biosecurity in poultry

Biosecurity is defined by the US poultry industry as "cumulative steps taken to keep disease from a farm and to prevent the transmission of disease within an infected farm to neighboring farms." (Hegngi 2003, p. 264). Biosecurity is a team effort, a shared responsibility, and an on-going process to be followed at all times. From the breeder to the hatchery, to growout operators, biosecurity measures have to be observed to contribute to the success of the industry. The major components of biosecurity, as practiced by the poultry industry, include: isolation, traffic control, sanitation, and rodent and insect control. The purpose of these practices is to prevent the introduction of pathogens and to provide the best living conditions for the health of the animals. In this way, the industry can minimize the risk of disease and insure the production of a clean food product. These principles can be applied to aquaculture practices in various ways to exclude the introduction of pathogens.

Biosecurity in aquaculture

Biosecurity in aquaculture has yet to be defined. It can mean different things to different stakeholders. Seafood consumers want to have an assurance that the product is safe to eat. Retailers have a responsibility to provide high quality seafood, and processors should follow Hazard Analysis and Critical Control Point (HACCP) guidelines to ensure that their products are safe for human consumption. At the farm site, workers need to know what practices decrease or increase the risk of a disease outbreak occurring. Investors seek to protect their investments from preventable losses. Indeed, the entire aquaculture industry is concerned about disease outbreaks. At the AIP Biosecurity workshop, practices at the industry level and policies in effect at the international and national level were discussed. Participants at the workshop defined biosecurity as "an essential group of tools for the prevention, control, and eradication of infectious disease and the preservation of human, animal, and environmental health." (O'Bryen and Lee 2003, p. 275).

The occurrence of disease is a combination of the health of the animal, the condition of the environment, and the presence of a pathogen. Klesius (2003) used the disease continuum model to illustrate how outbreaks of disease were the result of a weakened immune system of the culture animals, caused by neuroimmune changes resulting from stresses and infection. Therefore, excluding infectious agents and reducing stress are important in preventing disease outbreaks.

Biosecurity in shrimp farming

In general, biosecurity is more easily implemented in small, intensive, and controlled farming systems than in outdoor and large-scale operations (Horowitz and Horowitz 2003). Biosecurity measures in the shrimp industry can be seen as a two-pronged approach: excluding pathogens and eliminating pathogens when they are present.

Lightner (2003) discussed ways of excluding pathogens from stock (i.e., post larvae and broodstock), especially through the use of quarantine and specific pathogen-free (SPF) certified stocks, and restricting imports of live and frozen shrimp. Excluding vectors and external sources of contamination and preventing internal cross contamination were suggested methods for excluding pathogens from hatcheries and farms.

Horowitz and Horowitz (2003) described physical, chemical, and biological precautionary measures to be taken as well as a second line of defense against potential disease outbreaks. Physical measures are those that aim at preventing the intrusion of disease-carrying vectors to the farm site, and include physical barriers, water treatment, and quarantine. Chemical measures are those used to treat materials before they enter the facility. Chlorination and ozonization are often used to treat incoming water, and iodine and chlorine are used to treat other potential vectors such as tools, footwear, and clothing. Biological measures include the use of SPF shrimp, which are readily available commercially. A second line of defense for the shrimp industry is to use specific pathogen-resistant shrimp, which, in addition to being disease-free, are resistant to specific diseases. Since shrimp do not develop a specific immune response, common immunostimulants, such as β-1-3 glucan, lipopolysaccharides, and peptidoglycans are used to improve the ability of the shrimp to prevent infection.

If a disease presents itself at a particular pond, effective biosecurity measures should prevent the complete loss of the crop and the spread of disease to other ponds. Lightner (2003) recommended an approach to eliminating pathogens at the stock level and partial disinfection at the facility level. To eliminate pathogens in post-larvae and broodstock, affected tanks and ponds should be depopulated, disinfected, and restocked with SPF shrimp. It may, however, be necessary to depopulate the entire stock and to fallow the entire facility if partial disinfection (using lime, chlorine, or drying) is not successful.

Horowitz and Horowitz (2003) suggested providing better environmental and biological conditions to the infected population to increase its ability to resist diseases. They discussed the following steps: a) effect physical measures (increase aeration, control temperature, improve the feeding regime, remove sludge and organic matter, and treat wastewater) to improve the environmental conditions, b) effect chemical measures, including control of PH and salinity, reduction of ammonia and nitrite, and application of antibiotics, and c) to use effective biological measures, consisting mainly of the use of probiotics containing a mix of bacterial species to establish beneficial microbial communities under culture conditions.

Biosecurity in finfish

Examples of biosecurity measures in finfish culture were presented by Yoshimizu (2003), Kent and Kieser (2003), and Breuil et al. (2003). Yoshimizu (2003) addressed biosecurity measures used in Japan against viral diseases in salmonids and flounder (*Paralichthys olivaceus*, *Verasper moseri*). These control strategies include both physical and biological aspects. The physical aspects start with cleaning and disinfecting measures in hatchery and production facilities. The next step is disinfecting incoming water and wastewater. Fish viruses, which are sensitive to either UV or total residual oxidants (TRO), are inactivated by a treatment of 10^4 to 10^5 μ sec/cm^2 UV or 0.1 to 0.5 mg/mL TROs for 1 min (Yoshimizu 2003). Ozonated seawater that contains TROs, however, is toxic to fish and should be removed with charcoal. For treating large volumes of wastewater, such as those from hatcheries, electrolysis is very effective (Yoshimizu 2003). Carefully regulating water temperatures to between 15 °C and 18°C has been shown to be effective at reducing Japanese flounder (*P. olivaceus*) rhabdovirus (HIRRV) infectivity (Yoshimizu 2003). Dedicated equipment, nets, brushes, etc., are disinfected with ozonated or electrolyzed seawater containing 0.5 mg/L of total residual oxidants (TROs) or chlorine for 30 min. In terms of the biological aspects of disease control, broodstock undergo health inspections to ensure they are pathogen-free, and the health of the fry is routinely monitored. Larvae that are cultured in disinfected water may need to have a normal intestinal flora restored. Larvae that are fed with bacteria isolated from the normal intestinal flora showed anti-infectious hematopoietic necrosis virus (IHNV) activity under challenges (Yoshimizu et al. 1992). Immunizing stocks, using commercially available vaccines, is the most effective method for controlling salmonid diseases that cannot be excluded (Yoshimizu 2003).

In the mid-1980s, Atlantic salmon (*Salmo salar*) began being produced in British Columbia, and the industry now produces about 35,000 MT annually (Kent and Kieser 2003). The "eggs only" policy eliminates the introduction of many pathogens that require a live salmonid fish host. Any eggs that are imported into the area must have originated from certified specific disease-free sources, to ensure that diseases are not transmitted vertically. Kent and Kieser (2003) describe the methods that are used to disinfect Atlantic salmon eggs, which usually consists of 100 ppm iodine for 10 min. For species with eggs that require limited incubation time, eggs are disinfected with chlorine (0.6 mL 4-6% sodium hypochlorite/L) for 5 min. and then hatched in sterile water. Hatched larvae can be shipped under these conditions. Along with this policy, which also includes screening broodstock, disinfection, quarantine, and treatment of the effluent from quarantine facilities (5 ppm chlorine for 10 min and discharge to ground) are also included. As a result, nearly 23 million eggs have been safely imported into British Columbia since 1985.

In France, a pilot scale biosecure production system of sea bass (*Dicentrarchus labrax*) prevented vertical and horizontal transmission of nodavirus disease in broodstock to market size fish and avoided the use of antibiotics and anti-parasitic treatments, at a final production cost that was similar to traditional systems was presented by Breuil et al. (2003). Breuil et al. (2003) compared risk factors associated with the rearing of fish in various systems, and grouped them as meteorological events, such as storms and ocean swells, ecological events, such as plankton blooms and water pollution, pathological events, and other factors, such as mechanical problems. They concluded that recycling systems greatly reduce the risk of meteorological and ecological events except mechanical problems. By implementing biosecurity, the risk of pathological events can be reduced. The strategy combined the use of diagnostic tests for early detection and removal of nodavirus carriers to maintain healthy broodstock, control of specific bacterial populations in the recirculating system, i.e., use of a non axenic system, and treatment of wastewater with algae and reuse of the treated water (Breuil et al. 2003). Further mastering of the risks associated with rearing the fish in closed systems is possible. In general, treatment at the egg stage is expected to be the most effective.

Biosecurity in mollusc culture

Elston and War (2003) described the approach taken to biosecurity in mollusc culture in the US in terms of implementing health management and sanitation procedures for endemic diseases, and excluding non-endemic diseases. For endemic diseases, the health management procedures include assessing and understanding the state of health of individual and populations of cultured shellfish, early diagnosis of abnormal or pathological conditions, and preventing and correcting pathological conditions that may arise. Sanitation procedures are aimed at identifying and monitoring culture systems for contamination sources and management procedures to reduce or eliminate contamination. In intensive hatcheries and nurseries, pathogen-free algal stocks undergo surface sanitation in expanded culture and treated water is used with disease-free broodstock. Health assessments are critical at metamorphosis of larval mollusc cultures, and sanitation and health management are two of the keys to ensure production of healthy juveniles (Elston and War 2003).

Non-endemic infectious diseases are excluded from mollusc culture operations usually through regulations set by authorities. Elston and War (2003) describe the elements of a highly effective regulatory biosecurity program for shellfish in Washington State. This program facilitates the transfer of established species within Washington State with minimal permitting requirements, evaluates the importation of species established in Washington State with a health history from the West Coast commerce region, and requires increasingly rigorous requirements for importations from non-established sources and from outside the West Coast region. Regulations also restrict imported shellfish from being released into state waters and can only be propagated in an approved quarantine facility.

Potential disease vectors

Two potential disease vectors are airborne pathogens and gametes. Bishop et al. (2003) showed that a fish protozoan pathogen (*Ichthyophthirius multifiliis*) was transmitted by an aerobiological pathway to infect fingerling channel catfish (*Ictalurus punctatus*) at a distance of 91 cm from the pathogen source tank. Biosecurity countermeasures that were suggested include covering tanks and aquaria, erecting barrier walls, lowering the humidity around culture tanks where possible, and rerouting air currents. Tiersch and Jenkins (2003) discussed biosecurity risks from cryopreservation of sperm from aquatic species, including transmission of viral, bacterial, fungal, and parasitic agents, and the introduction of exotic species. Numerous regulatory frameworks are in place at state, national, and international levels for controlling the transfer of cryopreserved materials. The US Department of Agriculture's plant germplasm system (USDA 2003) provides a model that may be adapted for use with cryopreserved gametes from aquatic animals. Tiersch and Jenkins (2003) propose a germplasm repository system for fish sperm, based on three physical locations and databases: a) an archival repository cryopreservation center for frozen samples, with quarantine facilities to evaluate quality, verify species, and screen for disease, b) a satellite repository with facilities for duplicative storage, and c) a working hatchery, where samples are thawed, fertilized, and monitored for disease. They also show how this system could be integrated into existing biosecurity systems, such as the one used to develop SPF lines of shrimp. Suggested biosecurity procedures include physical separation of animals and gametes if diagnostic microbiology is performed at the same facility, decontamination of media that comes into contact with gametes, and the establishment of protocols for disposal of contaminated samples and for collecting, processing, storing, and transporting samples. Proper labeling and good record keeping are essential for a successful biosecurity program (Tiersch and Jenkins 2003).

Aquaculture biosecurity policies

Aquaculture biosecurity policies vary from farm-level to the international level, and between areas at each of these levels, but several characteristics are essential if aquaculture biosecurity polices are to be successfully implemented (Scarfe 2003). These common characteristics include: a) science-based decision making, b) economical and sociopolitical rationales, c) standardized and uniform methods, d) relative ease of application, e) wide recognition, f) vertical and horizontal integration, application, and agreement, g) consistent enforcement, and h) a primary focus on prevention, but with contingencies in place for control and management, or eradication.

A few of the major instruments for dealing with biosecurity at the global level are the World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement), the Food and Agriculture Organization of the United Nation's Codex Alimentarius and Codes of Conduct, and the International Council for the Exploration of the Sea's (CICES) Code of Practice on Introductions and Transfer of Marine Organisms (see Scarfe 2003, Table 1). The primary focus is on enhancing or protecting trade through biosecurity.

Issues regarding aquatic animal health are usually deferred to the Office International des Epizootices (OIE) (Scarfe 2003). Its mission is to inform governments of the occurrence and course of diseases throughout the world and of ways to control these diseases, to coordinate studies devoted to the surveillance and control of animal disease, and to harmonize regulations for trade in animals and animal products among its 158 member countries (D. Lightner, personal communication, July 2001). The *OIE International Aquatic Animal Health Code* and accompanying *OIE Diagnostic Manual for Aquatic Animal Diseases* (OIE Code and OIE Manual, respectively) are accepted by the member countries as international guides to preventing the movement of aquatic animal pathogens and diseases (Scarfe 2003). Key elements of the OIE Code in terms of biosecurity of aquatic animals include the General Provisions, the lists of diseases, and the section on Health Control and Hygiene. The General Provisions include general definitions, a section on Import Risk Analysis, and Import/Export Procedures. Lists of diseases of finfish, molluscs, and crustaceans are prioritized according to their significance because of their potential rapid spread, serious public health consequence, or importance in trade. The Health Control and Hygiene section includes procedures for disinfection of fish farms, mollusc farms, crustacean farms, and of fish eggs with iodine (Scarfe 2003).

At the national level, Australia has a comprehensive biosecurity program (AQUAPLAN) in place that provides an overall management strategy for aquatic animal health (Findlay 2003). This program applies integrated management strategies from the borders to individual farms or specific areas, with international linkages to OIE guidelines that have helped Australia to gain a trustworthy trade reputation. The Australian Quarantine and Inspection Service and Biosecurity Australia manage AQUAPLAN's quarantine program. Biosecurity Australia has an *Import Risk Analysis Handbook* (AQIS 1998) that details the process of import risk analysis, which is pivotal to every program within AQUAPLAN. The components, which are outlined in the SPS Agreement, generally involve a combination of qualitative or semi-quantitative risks and likelihoods of a disease incursion and its qualitative consequences (Findlay 2003). In descriptive terms, AQUAPLAN is a very conservative approach to quarantine risk, i.e., a very low acceptable risk for imported aquatic animals. Its success can be measured in improved aquatic animal health management in Australia, increased productivity and improved sustainability of its aquaculture, improved market access, and better protection for Australian aquatic ecosystems (Findlay 2003).

Conclusion

Biosecurity can be applied to aquaculture production systems through a variety of management strategies and by following internationally agreed upon policies and guidelines. In addition, there are a variety of risk assessments that can be used for aquatic animal diseases of finfish, molluscs, and crustaceans (Lee and Bullis 2003). The key elements of biosecurity can be summarized as reliable sources of stock, adequate diagnostic and detection methods for excludable diseases, disinfection and pathogen eradication methods, best management practices, and practical and acceptable legislation. Nevertheless, it is almost impossible to determine the economic benefits of a biosecurity program if there is no disease outbreak, and aquaculture producers may be reluctant to adopt biosecurity measures that appear to be an additional cost. A disease outbreak in one area, however, in addition to its economic consequences in that area, may cause unintended consequences in other parts of the world. The adage, "think globally and act locally" should apply to aquaculture production in the 21st century, as international standards for diagnosing and reporting diseases are adopted, methods for excluding diseases from culture systems are made integral to culture operations, and acceptable methodology for treating them is established.

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